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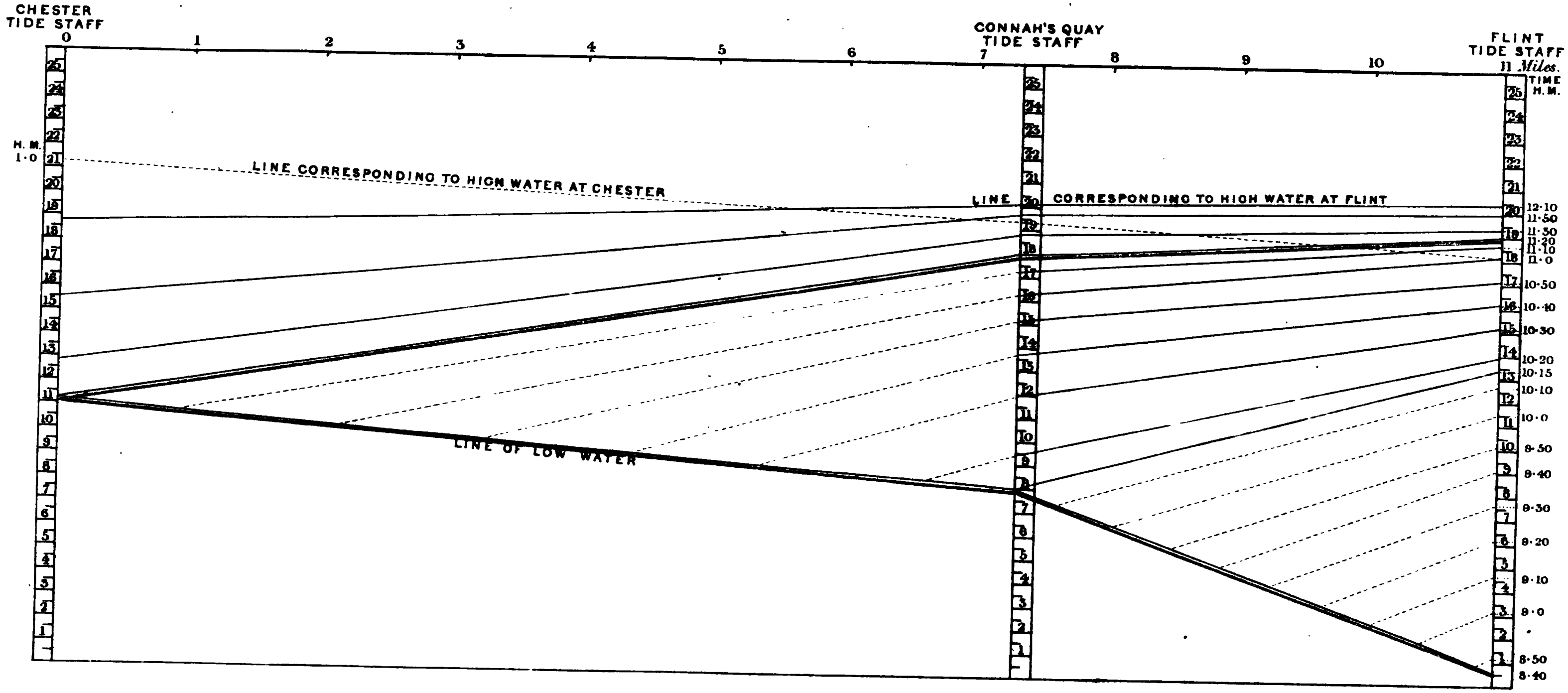
RIVER DEE.

FLOOD OF A SPRING TIDE.

Diagram shewing the approximate forms assumed by the Tidal lines of the River Dee, During the Flood of a Spring Tide rising 19 Feet 8 Inches at Flint.



James Andrews, Delt.

Geo. Aikman, Sculpt.

REMARKS

ON THE

IMPROVEMENT OF TIDAL RIVERS.

BY

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REMARKS, &c.

THOUGH the writings of Philosophers, and the reports of Engineers, from an early period, contain much valuable information regarding the improvement of inland navigation, yet the various theories, and even the practical opinions that have been advanced, are not a little discordant; and, hence, we find that authors, both of early and recent date, concur in expressing their conviction of the small degree of success by which both the theoretical and practical investigation of the subject, has hitherto been attended.

Professor Robison, for example, in his Treatise on the Theory of Rivers, makes the following observations:— "Such," says he, "having been our incessant occupation with moving waters, we should expect that the professional engineer would be daily acting from established principle, and be seldom disappointed in his expectations. Unfortunately, the reverse of this is nearly the true state of the case. Each Engineer is obliged to collect the greatest part of his knowledge from his own experience, and, by many dear-bought lessons, to direct his future operations, in which he still proceeds with anxiety and hesitation; for

we have not yet acquired principles of theory; and experiments have not yet been collected and published, by which an empirical practice might be safely formed. Many experiments of inestimable value are daily made; but they remain with their authors, who seldom have either leisure, ability, or generosity, to add them to the public stock."* And, again, Mr George Rennie, in his able Reports to the British Association on the State of our Knowledge of Hydraulics as a branch of Engineering, in alluding to the laws of rivers, says, "it is the office of science to unravel these mysteries; but although the attention of Philosophers has been directed to the attainment of a true theory, from the time of Galileo to the present, our knowledge of the laws which govern the motion of rivers is as yet very imperfect. The little success with which they have been investigated may be attributed to the difficulty of making correct observations, and to the local obstructions which generally exist in most rivers; and until we can ascertain those points correctly, by means of a series of careful experiments, we can only arrive at approximate results."†

Such was the state of our knowledge in this department of Engineering at the close of the last century, when Robison wrote, and such may still be said to be our information at the present day. And, in order to avoid misconception, it is necessary for me to state, that this communi-

* System of Mechanical Philosophy, by John Robison, LL.D., vol. ii. p. 389.

† Report on the Progress and Present State of our Knowledge of Hydraulics, as a branch of Engineering, by George Rennie, Esq., C.E. Transactions of British Association for 1834, p. 426.

cation has not for its object the advancement of any new *theory* or *principle* (a task which would, more naturally, fall within the province of the philosophical inquirer, than of the practical Engineer), but simply an exposition of the views by which I have been guided in designing different navigation improvements; and a statement of instances in which the works executed in accordance with these views have produced beneficial results.

I had occasion, in my Treatise on the Application of Marine Surveying and Hydrometry to the Practice of Civil Engineering, to refer, in illustration of the subject, to the tidal phenomena and physical characteristics of various Rivers and Firths with which I have been professionally connected.* But in that work I did not enlarge on the facts brought forward, or, indeed, do more than refer strictly to the means of acquiring the data necessary to enable the Engineer to form an opinion as to the practicability and probable expense of effecting desired improvements. In the present communication I have, therefore, availed myself, not only of the information contained in that Treatise, in so far as it is applicable, but also of that which is given in several professional Reports, which have from time to time been made; and I feel persuaded that this more extended view of the subject will not be considered out of place in this Society, as it may be interesting, and in some degree instructive, to the profession; while, in a purely theoretical point of view, ideas may perhaps be suggested, calculated to facilitate the determination of the

* Treatise on the Application of Marine Surveying and Hydrometry to the Practice of Civil Engineering. Edinburgh, 1842.

laws which regulate the motion of rivers; and thus to lead to the introduction of more definite and acknowledged principles for our guidance in conducting improvements on inland navigation.

The influx of the tidal wave through Firths or Bays, and the modification it receives in its passage up the inclined beds of rivers, produce two physical boundaries, which are found to exist in all rivers, when viewed in connection with the sea. These boundaries, again, produce three sections or compartments, to the improvement of only one of which the practical remarks I have now to offer refer, but it is necessary that they should be clearly defined, before proceeding to what has been sketched out as the special subject of observation. The seaward, or lowest of these sections, I have elsewhere termed the "sea proper;" the next, or intermediate one, into which the sea ascends, and from which it again withdraws itself, I termed the "tidal compartment of the river;" and the highest, or that which is above the influence of the sea, the "river proper." Their relative extent, in different situations, is influenced, not only by the circumstances under which the great tidal wave of the ocean enters the river, but by the size of its stream, the configuration and the slope of its bed, and, in short, by every natural or artificial obstruction which is presented to the free flow of the tidal currents along its channel.

These three compartments possess very different physical characteristics, and a totally different class of works is required for effecting improvements on them; and I shall endeavour to point out as distinctly, and, at the

same time, as briefly as possible, wherein these differences consist.

The presence of *unimpaired tidal phenomena* in the lowest; the *modified flow of the tide* produced by the inclination of the river's bed in the intermediate; and *the absence of all tidal influence* in the highest compartment, may be shortly stated as the physical characteristics by which these spaces are recognised. The tidal wave in the "sea proper" compartment, for example (although the place of observation be several miles embayed from what, in strictness, could be called the "sea" or "ocean"), is found, as regards both the amount of its range and its form, to be, practically speaking, identical with that of the adjoining seas; while the identity between the tidal phenomena is farther strikingly exemplified by the practically level line preserved by the low water mark, and by the shortness of the time which elapses between the cessation of ebbing and the commencement of flowing; or, in other words, the absence of any protracted period of low water, during which the sea appears to remain stationary at the same level. In ascending into the intermediate compartment, however, the level of the low water is no longer the same, the range of tide, excepting in peculiar cases, becomes less, and is gradually decreased, as the bed of the river rises; and, at length, a point is reached where its influence is not perceptible. In this intermediate section, the phenomena of *ebbing* and *flowing*, and the consequent reversal of the direction of the currents, take place; but the times of ebb and flood do not remain constant; that of ebb gradually gaining the

ascendancy; and the continuance of low water being gradually protracted as we proceed upwards, until the existence of tide is unknown. This forms the boundary line of the upper compartment, the characteristic of which is, the total absence of ebbing and flowing, the river at all times pursuing its downward course in an uninterrupted stream. In the investigation of these different characteristics, the variable nature of the elements to be dealt with must be kept in view;—the river, for example, is liable to be affected by floods, and the state of the tides by winds and other causes; and, therefore, a great degree of precision in defining these spaces cannot, in all cases, be expected, nor, indeed, is such necessary for the purpose of the present inquiry. But it is satisfactory to know that the termination of the low water level at the separation of the seaward and intermediate spaces, as laid down by Marine Surveyors, simply from observation of the tidal phenomena, has, in several situations, been found to agree exactly with the position of that boundary, as determined by Engineers, by means of accurate levelling, combined with careful tidal observation.*

The remedial means which call for the Engineer's consideration are, as I have already hinted, not less distinct than the physical characteristics which I have endeavoured to describe. The seaward compartment embraces all works connected with the removal or improvement of bars. The tidal compartment embraces a more varied range, including the straightening, widening, or deepening, of the

* The Rivers Mersey and Ribble, and the Firths of Cromarty and Dornoch, may be stated as examples.

courses and beds of rivers, the formation of new cuts, the erection of walls for the guidance of the tidal currents, and, in some cases, the shutting up of subsidiary channels. The works on the river proper section, again, consist chiefly in the erection of weirs, by means of which the water is dammed up so as to form, in favourable situations, extensive stretches of canal in the river's bed, the communication between the different reaches being effected by locks formed in the weirs; a system which has been very extensively introduced in North America, where limited means, and abundance of fine streams, rendered it peculiarly applicable. It is my intention at present, however, to confine my remarks to the intermediate or tidal compartment only, which, it will be admitted, possesses sufficient importance to entitle it to form the subject of a distinct communication, when it is considered that some of the principal Harbours of the Kingdom, and many smaller, but rising places, are entirely dependent on the continued facility or increased efficiency of its navigation; for instances of which, the Ports of London, Bristol, Newcastle, Preston, Glasgow, Perth, Lancaster, Chester, and many other places, may be named.

The Mississippi, St Lawrence, and other gigantic streams, which pour down an amount of fresh water sufficiently great to afford, at all times, ample breadth and depth for the purposes of navigation, form a striking contrast to the rivers of this comparatively narrow country, which, from the smallness of their discharge, can be advantageously navigated only while their waters are deepened by the influx of the tide, and are consequently closed to all vessels,

excepting those of the smaller classes, during the absence of tidal influence.* Our rivers may, therefore, be viewed as narrow inlets or creeks, formed and kept open by the joint action of the fresh water stream and the tide. In many cases the action of the fresh water stream may, by certain operations, be rendered more effective in keeping open the channel in which it flows; but it is evident that the volume or amount of discharge will remain a constant quantity, and cannot be augmented by works of art; and in dealing with such localities, the Engineer must therefore direct his endeavours to produce an *increase in the duration of tidal influence*, as the surest means of effecting improvement. Although every case must undoubtedly be considered *per se*, yet it will be found that this important end may, to a certain extent, be attained in all instances, by lowering the bed of the river, and removing all obstruction to the free flow of the tide, so that the propagation of the tidal wave through the channel may be accelerated; and it may safely be affirmed that the more rigidly that class of works is adhered to, the more *generally* beneficial will be the effect produced; for not only do they improve the part of the river where they are executed, but they operate beneficially throughout its whole course, their tendency being *to increase the backwater by which the sea channels are kept open*, which is the object to be chiefly aimed at in

* At Pittsburgh, on the Ohio, a tributary of the Mississippi, I have seen, at once, from 30 to 40 steamers, varying from 300 to 700 tons burden, drawing from 6 to 8 feet of water, moored in the river, and all engaged in trading to New Orleans, distant 2000 miles by the course of the river, which is uninfluenced by the tide. Stevenson's Sketch of Civil Engineering in North America. London, 1838.

designing works for the preservation or improvement of the "sea proper" sections of rivers.

Smeaton, Golburne, and other early Engineers, and even some of later date, not sufficiently impressed with the importance of these principles, have proposed to improve tidal rivers by means of works which are subversive of their best interests. Smeaton, in the year 1755, when consulted in the case of the Clyde, proposed the erection of a dam with locks at Marlinford, below Glasgow. Since the period, however, when this suggestion was made, our practice in Engineering has been considerably altered and extended, by growing experience, as well as by the powerful aid now received in all such operations from the application of steam power, both to dredging harbours and rivers and to towing and propelling vessels. It will not, therefore, I trust, appear to be throwing any reflection on the Father of British Engineers, to say that, had the work which he contemplated been executed, the channels seaward of the dam would have been to a great extent choked up, and Glasgow never could have stood, as it now does, at the head of Scottish ports. Golburne, with the view of narrowing the stream, and thus producing a greater scouring power to operate on the bottom, designed the projection of a succession of jetties or groins from the banks. It is no doubt true, that the projection of jetties into the stream accelerates the current, and occasions a considerable increase of depth in their immediate vicinity, but the increased velocity produced is not regularly, or indeed for any great distance, kept up: a partial stagnation of the water taking place, and a bank or shallow being

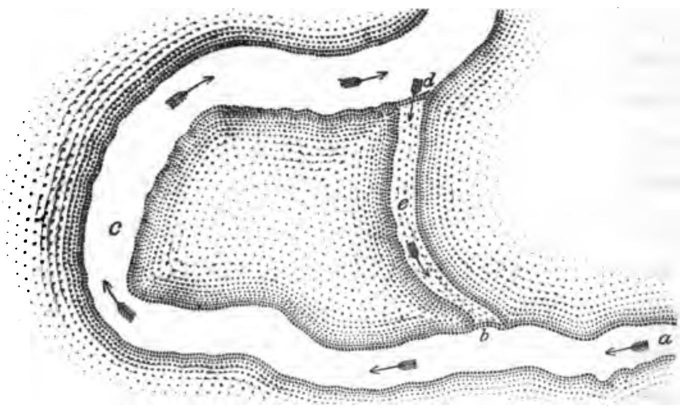
thereby formed. The consequence is, that a river so treated, is found, in a short time, to consist of an alternation of shoals and deep pools, instead of presenting a regular bottom and an uniform depth of water, which, although it may at no place be so deep as in the pools formed by the different jetties, is nevertheless, in no instance, so shallow as on the shoals between them, and is thus more available for the purposes of navigation. Examples of this effect being produced are to be met with in the history of the Clyde, the Ribble, the Dee in Cheshire, the Tay, and, I believe, with very little exception, in all situations where the system of contracting or even directing the currents by means of jetties has been carried to any extent. From the Clyde and the Ribble they have now been almost entirely removed,—from the Clyde, by the advice of the late Mr Rennie; and from the Ribble, under my own direction. In both places extensive and systematic works on that principle had been executed, and their removal has been attended with great advantage. On the Dee they still remain, and from the lower part of the Tay they are now in course of being removed.

Before entering more particularly on the works by means of which the propagation of the tidal wave may be accelerated, and the duration of tidal influence increased, it may be proper to enumerate the causes which are most frequently found to operate in producing its retardation. These may be stated to be the circuitous routes of the channels of rivers, the slopes of their beds, the projection of obstacles into the stream, and the downward flow of the fresh water. The combined effect of these ob-

structions is such, as in all rivers, and more especially where there is a great and rapid rise of tide, to cause the tidal wave to be heaped up in the lower part of the river, and thereby to give rise to *bores* and other apparent anomalies, which occur in such situations. In the Dee, for example, at low water, there is a fall of 11 feet from Chester to Flint, a distance of 12 miles; and, on one occasion, I found that after the tide had risen 18 feet 4 inches at Flint, it had not commenced to flow at Chester. While, therefore, at low water there is a fall of 11 feet from Chester to Flint, there was, at the time alluded to, a fall of no less than 7 feet 10 inches, from Flint to Chester, caused by the heaping up of the water in the lower part of the river, in consequence of the obstruction presented to the propagation of the tidal wave up to Chester. In Plate II. the lines of this tide are shewn; those coloured red represent respectively, the state of the river at low water, and at the time of tide alluded to. For a more detailed description of these phenomena, I must refer to the Treatise on Marine Surveying, already quoted, and to the writings of Mr Russell,* whose Researches on Hydrodynamics have been of the greatest service to Engineering. But before passing from this subject, I may be excused for introducing a circumstance, which appears to me to illustrate the retardation of the tidal wave in a very obvious and forcible manner.

* Researches on Hydrodynamics, Transactions of the Royal Society of Edinburgh; and Reports by Committee on Waves to the British Association.

In the accompanying diagram, the letters *a b c d* represent a part of the low water channel of the river Dee, at a place



where the estuary is about 3 miles wide, and consists of extensive sandbanks. In examining minutely the windings of the stream, in reference to certain investigations, it was necessary to walk down the right bank of the river at low water, close to the edge of the channel. While so engaged, I crossed, at the point *b*, a hollow in the sandbank, which, though depressed below the general height of the surrounding surface, was nevertheless quite dry, the lowest part of the track being considerably above the level of the water in the river. I had only advanced a few paces, after crossing this hollow, when I heard the rushing noise of the approaching tide. Expecting to meet the flood forcing its way up the river, I continued to walk on; but seeing no appearance of its approach by the proper channel, and still hearing the noise gradually increasing, and apparently coming from behind me, I turned

round, and to my great surprise, perceived a rapid run of water flowing (in the direction shewn by the arrow) through the hollow *d e b* which I had just crossed, and emptying itself into the river at *b*. I immediately hastened back towards the boat which waited for me a little higher up, and after having waded through the newly formed stream at *b*, which had attained a depth of six or eight inches, I waited on its upper side to see the result of this unexpected inroad. The water continued to rush through the hollow, rapidly gaining breadth and depth; and, at last, after an interval of two, or two and a half minutes from the time at which the noise was first heard, the tide appeared forcing its way up the proper channel of the river; and having dammed back the current which rushed through *d e b*, the sandbank *b c d* was soon encircled by a broad and deep boundary of water, rendering all communication with it, without a boat, quite impracticable.

An explanation of the cause of this phenomenon may be found in the heaping up of the tide, to which I have already alluded. The level of the water at Flint, as already stated, was found on one occasion to be seven feet ten inches above that in the upper part of the river, its surface forming an inclined plane downwards from the sea towards Chester; it may, therefore, be concluded that, in the early periods of tide, the level of the water at *d* in the Diagram would be above that at *b*. The tide on arriving at the point *d* would be naturally divided into two branches or currents, one proceeding up the channel towards *c*, and the other flowing into the hollow in the sandbank at *d*, towards *e*; and, as the level of the water at *d* rose, the stream

which flowed into the hollow in the sandbank would gradually rise higher until it surmounted the summit level at *e*, after which it would rush from *e* to *b* without obstruction. The other branch of the tide would, in the mean time, be forcing its way against the stream of the river along the circuitous channel *d c b*, which was about a mile in length; and having a longer course to run, as well as greater friction, and the current of the fresh water to contend with, its approach was obstructed, so that before it reached *b*, the water at *d* had attained a much higher level than that at *b*, and having surmounted the summit level of the sandbank at *e*, continued to flow without obstruction into the channel of the river, in the manner represented. Thus, in all places where the retarding influences which exist in the regular channel of the river exceed the obstructions in any *back lake* or *swash way*, the tide will flow sooner through the latter than the former, and give rise to an apparent anomaly, such as I have described.

The removal of these retarding influences is the object to which, as already noticed, the Engineer has chiefly to direct his attention in designing improvements in the department of navigation now under consideration; and it may be stated, that, in order to form a satisfactory opinion on this matter, it is essential to have an accurate survey, shewing the depths of water and breadths of channel throughout the whole extent of the river, and also to ascertain the amount of tidal range, the velocity of the currents, the rise on the bed, and the nature of the materials of which the bottom and banks are composed. Possessed of this information, we are in a position to

consider to what extent the bed of the river may, with advantage, be deepened and widened, and the currents directed by means of walls; also if subsidiary channels may, with safety, be shut up, or new cuts be made for the passage of the river; or whether or not irregularities in the width, which injuriously affect the currents, may be corrected. In all these matters we must, in each particular case, be guided, in a great measure, by experience, there being, as expressed in the quotations from Professor Robison and Mr Rennie, no universally acknowledged laws, founded on mathematical investigation, or practical experience, which we can call to our aid. It is therefore impossible to specify works which shall be of *universal* application; but I am desirous of directing attention to certain works which have, in some cases, been beneficial; the more so, as experience has convinced me that their adoption will be found to be more generally productive of benefit than is perhaps at present acknowledged.

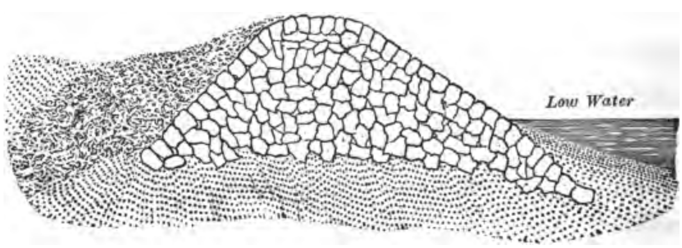
With reference to these operations, it may be stated, that all obstructions which prevent the extension of the tidal influence up the river may safely be taken away, and their removal may confidently be expected to be followed by highly beneficial effects. It is necessary to remark, however, that the removal of artificial weirs erected for the purposes of manufacture, is, in many cases, attended with difficulty, arising from the value of the interests involved, which are sometimes so great that their abolition cannot be effected without the payment of a large amount of compensation to the proprietors. The weirs on the Dee in Cheshire, and the Lune in Lancashire, are in-

stances of this, being productive of much injury, while, in both cases, the consequences attending their removal are so formidable, as hitherto to have placed that important step beyond the reach of those interested in the trade of the rivers. The removal of existing quays, and other works of long standing, as in the case of the Thames and the Tyne, is also, for the same reason, difficult; and works must therefore be designed for such localities which shall not injuriously affect existing interests. But all natural weirs, or shoals consisting of fixed rock, or hard gravel, which cannot be disturbed by the action of the current, as well as all projections into the stream, where unattended by the difficulties alluded to, should at once be removed. In rivers where small islands occur dividing the currents into separate branches, reducing their volume, and decreasing their scouring power in the navigable channel, fords or shoals are generally produced; and it will be found advantageous, in such cases, to shut up the subsidiary channels, and probably to enlarge the main channel, to compensate for that which has been closed, and assimilate its cross sectional area to the rest of the navigable track. In the lower part of rivers where the banks expand, leaving the stream to find its way by a tortuous course through sandbanks, low rubble walls may, with advantage, be applied to guide the currents of the first of flood and last of ebb, and thus to fix the navigable channel in a defined and permanent track. The bed of the river, where the slope admits of it, should be lowered by a properly directed system of deepening, and the operation of harrowing the bottom, so as to disturb the mate-

rials of which it is composed, and enable the current to float off the smaller particles into deep water, may also be employed; but this latter method of working is more generally applicable in the sea proper compartment of navigation.

These may be said to be the safest and most beneficial works which can be adopted in designing river improvements. The manner in which they are executed demands a few remarks. The last mentioned process of deepening and clearing the bed is probably that which is most important and of most general application. It is now invariably effected, where the nature of the materials admits of it, by means of the Steam Dredge. A well constructed Dredge of sixteen horses' power will, under favourable circumstances, raise 140 tons of stuff per hour, and the price may be taken at 4½d. per ton, including discharging the Ponts or Lighters, which is nearly as small a sum as that for which it can be excavated above water by manual labour. The removal of rock, or large collections of boulder stones, or of any material too hard or too large for the dredge buckets, may be effected by means of the coffer dam or diving bell; and, in some situations, much may be effected by blasting under water by means of the patent fuze, and removing the materials by cranes fixed on lighters. In the improvement of the Ribble navigation, upwards of 30,000 cubic yards of rock *in situ*, were excavated from the bed of the river, by means of coffer dams; and from the Erne in Ireland, upwards of 5000 tons of boulders and fixed rock were removed, in a depth of water, varying from one to five feet, by the use of cranes on ponts and

hand dredges. Large boulders, with which the beds of many rivers are encumbered, occasion considerable trouble in their extraction. They are generally blasted, and removed piecemeal, by means of cranes; but sometimes they are raised *en masse*, by the floatation of ponts; and, in this way, boulders of fifty tons weight have been raised from the Tay. In situations where there is not much exposure to currents, subsidiary channels may be shut up by embankments formed of the stuff dredged from the river, provided it consists of gravel, or other heavy matter capable of resisting the action of running water; but, in making embankments, or rather walls, for the direction of the current in open and exposed situations, more substantial work is necessary, and they may be best composed of large sized rubble stones, which, after they have sufficiently subsided, are properly paved. These walls may be from 3 to 5 feet above low water mark, and when covered by the tide their position is indicated by beacons placed at short intervals apart. The line of their direction must be judiciously determined, and carefully staked out for execution. Their size depends much on the nature of the ground on which they are built. They have been extensively employed by Mr Walker on the Clyde, and the accompany-



ing Diagram represents the cross section of those on the Ribble, where nine miles of walling have been erected.

I come now to give a brief sketch of Navigation Improvements executed in accordance with these general views, and to shew their application in practice, and the effect produced by them; and I shall, first, allude to the river Tay, as I know no instance in which the improvements effected by particular works are more fully and satisfactorily demonstrated by a comparison of observations made *previously* and *subsequently* to their execution, than in the case of that navigation, where the changes were brought about in so short a time, and were so marked as to leave no doubt, even to superficial observers, of their attainment, and no difficulty, by the use of proper means, in ascertaining their amount.

The river Tay with its numerous tributaries, receives the drainage water of a district of Scotland which, as measured on Arrowsmith's Map, extends to 2283 square miles. Its *mean* discharge has been ascertained to be 273,117 cubic feet, or 7621 tons of water per minute.* It is navigable as far as Perth, which is 22 miles from Dundee, and 32 from the German Ocean. The different points on the river hereafter to be referred to will be seen by examining Plate No. 1, for the use of which in illustrating the subject, I am indebted to the Perth Harbour Commission.

It would be tedious, in this place, minutely to detail the tidal phenomena of the Firth and River; which were carefully investigated previous to the commencement of the

* The discharge of the Thames at Teddington Weir is 80,220 cubic feet, or 2238 tons of water per minute, being less than one-third of that of the Tay. Report on Hydraulics, by G. Rennie, Esq.

works, the object of this communication being to point out what these works were, and the effect produced by them.*

Before their commencement, certain ridges called "fords" stretched across the bed of the river at different points between Perth and Newburgh, and obstructed the passage to such a degree, that vessels drawing from 10 to 11 feet could not, during the highest tides, make their way up to Perth without great difficulty. The depth of water on these fords, the most objectionable of which were six in number, varied from 1 foot 9 inches to 2 feet 6 inches at low, and 11 feet 9 inches to 14 feet at high water of spring tides; and, in addition to the shoalness of the water, many detached boulder stones lay scattered over the bottom. Numerous fishing-cairns, or collections of stone and gravel, had also been laid down without regard to any object, but the special one in which the proprietors of the land were interested; and in many cases they formed very prominent and dangerous obstructions to vessels. The chief disadvantage experienced by vessels in the unimproved state of the river was the liability that existed of their being detained by grounding, or being otherwise obstructed at these defective places, so as to lose the tide for Perth,—a misfortune which, at those times when the tides were falling from springs to neaps, often led to the necessity either of lightening the vessel, or of detaining her till the succeeding springs afforded sufficient depth for passing the fords. The great object aimed at, therefore, was to remove every cause of detention, and facilitate the propagation of the tidal wave

* For this, reference is made to the Report by R. Stevenson and Sons, of 7th January 1845, addressed to the Lord Provost and Magistrates of Perth.

in the upper part of the river, so that inward bound vessels might take the first of the flood to enable them to reach Perth in one tide. Nor was it a less important end to remove every obstacle that might prevent outward bound vessels from reaching Newburgh and the more open and deep parts of the navigation, with the tide by which they were enabled to leave Perth.

The works undertaken by the Harbour Commission of Perth for the purpose of remedying the evils alluded to, and which extended over six working seasons, may be briefly described as follows :—

1st, The fords and many intermediate shallows were deepened by steam dredging; and the system of harrowing was employed on some of the softer banks in the lower part of the river. The large detached boulders and fishing-cairns which obstructed the passage of vessels, were also removed.

2d, Three subsidiary channels at Sleepless, Darry, and Balhepburn Islands, the positions of which will be seen on the Plan, were shut up by embankments formed of the produce of the dredging, so as to confine the whole of the water to the navigable channel.

3d, In some places, the banks on each side of the river, beyond low water mark, where much contracted, were excavated and removed, in order to equalize the currents, by allowing sufficient space for the free passage of the water; and this was more especially done on the shores opposite Sleepless and Darry Islands, where the shutting up of the secondary channels rendered it necessary.

The benefit to the navigation, in consequence of the com-

pletion of these works, has been of a twofold kind : for, not only has the depth of water been materially increased, by actual deepening of the waterway, and the removal of numerous detached obstructions from the bed of the river, but, by a clearer and freer passage for the tidal currents having been afforded, the tide now begins to flow at Perth, sooner than before, while the time of high water remains nearly the same ; and thus the advantages of increased depth, due to the presence of the tide, are proportionally increased throughout the whole range of the navigation, or, in other words, the duration of tidal influence has been prolonged.

The depths at the shallowest places are now pretty nearly equalized, being 5 feet at low and 15 feet at high water of ordinary spring tides ; instead, as formerly, of 1 foot 9 inches at low, and 10 feet at high water. Steamers of small draft of water can now, therefore, ply regularly at *low water*, and vessels drawing 14 feet can now come up to Perth in *one tide*, with ease and safety. In the completion of these improvements, the Harbour Commission has expended upwards of L.53,000, and about 841,480 tons of material have been raised from the bed of the river.

In obtaining the requisite data, as to the design and execution of the works, minute tidal observations have, at various times during the last ten years, been made at different stations throughout the River and Frith of Tay. These observations have, from time to time, as occasion required, been compared amongst themselves, and their results obtained. But it was lately found necessary, with reference to a more extended inquiry, to analyze the whole

afresh. This investigation proved to be one of considerable labour, and the general results deduced, which I have appended to this communication in a tabular form, shew, by the favourable change which has been effected in the tidal phenomena of the estuary, that the works hitherto executed have fully answered the intended end. Three very important changes have taken place, to which I wish to direct attention.

First, It will be observed, by an examination of the Table, that the fall on the bed of the river, from the Tide Basin at Perth to Newburgh, in the year 1833, was *four* feet; but now it is only *two* feet.

Second, In 1833, the passage of the tidal wave from Newburgh to Perth (8.56 miles) occupied 2 h. 30 m., being at the rate of 3.42 miles per hour; but it is now propagated between the same places in 1 h. 40 m., being at the rate of 5.13 miles per hour; giving a *decrease* in the time of 50 m., and an *increase* in the speed of the first wave of flood of more than $1\frac{2}{3}$ mile per hour since the commencement of the works.

Third, The spring tides in 1833, at Perth, flowed 2 h. 20 m., ebbed 7 h.; and at low water the river ran at its natural level, 1 h. 45 m.; but now the tide flows 3 h. 10 m., ebbs 7 h., and stands at low water only 1 h., being an *increase* in the duration of flood of 50 m., and a *decrease* in the time at which the river is uninfluenced by the tide of 45 m.

These tables farther afford some interesting results as to the present state of the propagation of the tidal wave in the Tay, in connection with the obstruction it receives at

different parts of the riyer. We find, on examining the Tables, that the velocity of the wave in the different reaches of the river is as follows:—

	Miles per hour.
From Dundee to Balmerino the velocity is	18.75
Balmerino to Flisk Point, ...	6.06
Flisk to Balmbreich, ...	4.69
Balmbreich to Newburgh, ...	3.86
Newburgh to Carpow, ...	3.17
Carpow to Kinfauns, ...	5.36
Kinfauns to Perth, ...	6.93

From these results, it evidently appears, that the part of the river in which the propagation of the tidal wave is now most retarded lies between Flisk Point and Carpow, between which places the average velocity is only 3.51 miles per hour. In the practical working of the navigation, indeed, the deficiency at this place has become more apparent, and is more complained of by shipping since the improvements *above* have been felt and valued. In the lower part of the navigation, from Balmerino to Flisk, the velocity, as appears from the tables, is 6.06 miles per hour; and in the upper part, from Carpow to Perth, the average is 5.78 miles; so that the intermediate space, from Balmbreich to Carpow, being only 3.51 miles per hour, forms a marked contrast to any other section of the tidal course of the river.

On the first view of the subject it might be supposed, that the division of the stream at Mugdrum Island, or the junction of the Earn, might account for the diminution of

velocity in the tidal wave which takes place at that part of the river. But, after duly considering the navigable channel on the *south* side of Mugdrum Island, with reference both to the inclination of its bed and its contour, and taking into account the more generally shallow and varied depth, and irregular cross sectional area of the *north* channel, I am of opinion that the retardation of the first tidal wave of flood is to be accounted for, not by the division of the stream into two channels, but by the obstructions opposed to its progress in the present south or navigable channel, from Balmbreich to Carpow, as compared with that of the upper and improved part of the River.

The obstructions in the part of the navigation to which I refer are of two kinds, namely, the amount of fall on the bed of the river, and the rugged and tortuous line of channel along which it flows.

The fall on low water, as may be easily imagined, forms, in proportion to its amount, a serious bar to the propagation of the tidal wave. This I have ascertained in the Lune, Dee, Wyre, and other rivers and firths, which I have surveyed. As regards the Tay, the following results with reference to this point are given in the Table. The rise on low water spring tides, from

	Ft.	In.		Slope. In. per mile.
Flisk Point to Balmbreich is	0	4	or	1.95
Balmbreich to Newburgh, .	2	8	„	9.35
Newburgh to Carpow, . .	0	5	„	3.75
Carpow to Perth, . .	1	7	„	2.63

From these results, it appears that, between Balmbreich

and Newburgh, the place where, as we have already seen, the passage of the tidal wave is slowest, there is a rise of 9.35 inches per mile, which is nearly three times greater than on any other part of the river. The other obstructions referred to are of a nature not less serious. Many jetties had from time to time been projected from the south shore, for purposes connected with reclaiming and protecting the land. These jetties (which, as decided in a late Process at Law between Lord Zetland and the Conservators of the river, are now in course of being removed, under a decree of the Court of Session) extended so far into the navigable channel as to prove great obstacles to the flow of the tide, as amply exemplified by the alternate shallows and deep pools which they occasioned; and, even now, although great part of them has been removed, the tortuous and irregular channel, caused by their projection into the *fair way*, has not yet been brought into train.

From a consideration of these facts, a series of works for the farther improvement of the navigation was lately submitted to the Conservators. For the lower part of the river, a line of conservation for the margin of the channel was proposed, by the erection of a system of rubble walling, instead of the present irregular and broken line of shore, formed by the protrusion of jetties into the stream. Were such a wall carried in a judicious line of direction, from a point near the junction of the Earn to a point at or near Flisk, the level of the low water between Newburgh and Balmbreich would soon be lowered; and the present obstruction to the passage of the tidal wave being re-

moved, its propagation would be greatly accelerated. This change would, of itself, operate beneficially on the whole line of navigation to Perth, at which place the first of flood would be hastened, in proportion to its earlier appearance at Newburgh, while the scour would be rendered more effective. In connection with this work, the continuance of dredging for the upper part of the river was farther recommended; and if these works were carried out, it is confidently expected that a depth of from nineteen to twenty feet at high water of ordinary spring tides up to Perth would be obtained, instead of ten or eleven feet as formerly. It will be observed that these works can be executed without abstracting or in any way interfering with the back water of the river, which would indeed be increased; and thus the sea channels of the frith would be improved, and all questions as to injuriously affecting other interests would be avoided. It is not easy to obtain a very satisfactory result in endeavouring to estimate the increased influx of tidal water in the Tay, due to the changes on the tidal phenomena produced by the works already completed; but, according to calculation, proceeding on what I consider to be tolerably correct data, it appears that, *during every tide*, an *additional* quantity of sea water, amounting, on an average, to not less than one million cubic yards or about 760,560 tons, is propelled into, and again withdrawn from, that part of the river extending above Newburgh. The effect of this increase on the sea channels must be highly beneficial.

For one other example of decided improvement, I shall

refer shortly to what has been done on the Ribble. That river, according to Mr Park, who conducted, as resident engineer, the greater part of the works, has a course of 82 miles, and drains 900 square miles of the counties of York and Lancaster. The formation of the bed in which it flows rendered the state of the tidal compartment, previous to the improvements, very defective. The bottom, in the lower part of the river, consists of loose sand, while that of the upper reach is alternately compact gravel and sandstone rock. About half a mile below Preston, in particular, it was found that a solid band of sandstone, extending to 300 yards in length, stretched quite across the channel. Its surface was from three to five feet higher than the general bed of the river both above and below it; and so prominent an obstruction did it form, that the higher parts of the rock were occasionally left dry during the long droughts of summer. The propagation of the tidal wave, and free flow of the currents, were checked on approaching it, while the power of the tidal and fresh water scours was, in a great measure, neutralized, and rendered almost unavailable, in keeping open the upper and lower stretches of the navigation, so that its influence in obstructing the river resembled that of a great artificial weir stretched across the stream. In proof of this, it may be stated, that the ordinary rise of spring tides at Lytham, which is twelve miles seaward of Preston, is about nineteen feet, and that of neap tides fourteen feet; while, at Preston, prior to the operations, the rise of spring tides did not exceed six feet; and neap tides

of thirteen or fourteen feet rise at Lytham did not reach Preston at all.* The removal of the rock which encumbered the bed was naturally viewed as the most urgent and important work for effecting an improvement in the tidal phenomena, and general depth of water. To this, therefore, the Navigation Company first directed its attention; and, in the course of eighteen months, succeeded in excavating a channel through the solid rock 300 yards in length, and, in some places, thirteen feet six inches in depth. This operation was successfully accomplished at an expense not exceeding L.10,000, by means of a coffer dam of peculiar construction, designed by me for the purpose, of which a particular account will be found in the Transactions of the Institution of Civil Engineers.† In addition to this work, about 480,000 tons of gravel and sand have been removed from the upper part of the river by dredging; and, as already noticed, nine miles of low rubble walling (formed, in so far as it was available for the purpose, of the rock excavated from the bed of the river) have been constructed, in accordance with the sketch at page 20, for guiding the current in the lower channels.

I have at present in view to make a series of observations on the Ribble, which will enable me to contrast, in a tabular form, as I have done in the case of the Tay, the former and present tidal phenomena. In order, however, to shew the effects of the different works that have been

* Captain Sir Edward Belcher, while engaged in making the Admiralty survey of the Ribble, found that, on one occasion, the tide at Lytham rose 25 feet 7½ inches.

† *Vide* vol. iii. p. 377.

executed, it is, perhaps, sufficient to state generally, that the amount of tidal range at Preston has been increased between *three and four feet*, and that the propagation of the tidal wave has been accelerated about *forty minutes.* The beneficial effects of these changes are apparent in the increased trade of the port, the tonnage dues having been quadrupled since the commencement of the operations; and vessels, to which the navigation may be said to have been previously closed, now come up to the quays of Preston, with comparative ease and safety.

Having noticed the changes which have been produced on these important rivers, at an expenditure, in the one case not much exceeding L.50,000, and, in the other, L.40,000, I have now only, in conclusion, to recapitulate the practical inferences that may be drawn from the facts brought forward. These appear to be,

First, That owing to the comparatively contracted country from the drainage of which our rivers derive their supplies, it is chiefly from *increased duration of tidal influence* that we must expect improvement in tide navigation, the regulation of the fresh water stream being an operation of secondary importance, but not, on that account, to be overlooked.

Second, That the whole tidal phenomena of the navigation to be improved ought to be ascertained, in order that the Engineer may be enabled to discover in what part of the river the most prejudicial retardations of the tidal wave, and obstructions of the current, take place.

Third, That, in tracing these retardations to the proper cause, and suggesting means for their removal, works

should be adopted which do not injuriously abstract tidal water from the sea channels.

Fourth, That the works best suited for attaining the desired end consist chiefly in lowering the bed of the river, and removing all natural or artificial obstructions, and in erecting low rubble walls for the direction of the currents.

Fifth, That although *general* views of the nature of these operations may be given, the precise details of such works as shall be best suited to particular localities can, in the present state of our information, be determined only by Engineering experience. And,

Lastly, That, by the execution of works designed in accordance with these general views, very beneficial results have been, and may be, produced, for a comparatively small expenditure.

In bringing these remarks before the Royal Society, my object has been the advancement of that branch of civil engineering which relates to the improvement of inland navigation, a subject which has occupied, as already noticed, the attention of Engineers and Philosophers from the earliest times; and I shall be glad if my humble efforts, by suggesting ideas to others who have leisure and inclination to prosecute the inquiry, shall be found to contribute, in any respect, to the attainment of this most important and desirable result.

EDINBURGH, *22d February* 1845.

APPENDIX.

RESULTS of OBSERVATIONS made at various times, from 1833 to 1844 inclusive, on the Tides of the River and Frith of Tay.

I. *Propagation of Tidal Wave.*

TABLE of elapsed times, between arrival of the Tide wave at the following stations, during Spring Tides in 1833 and 1834, shewing the rate of its propagation :—

	Time. H.	Time. M.	Distance in Miles.	Rate of Tide-Wave in Miles per Hour.
Dundee to Balmerino, ...	0	16	5.00	18.75
Balmerino to Flisk Point, ...	0	29	2.93	6.06
Flisk Point to Balmbreich, . .	0	26	2.04	4.69 - 4.7
Balmbreich to Newburgh, . .	0	53	3.42	3.86 - 3.87
Newburgh to Perth (Tide Harbour),	2	30	8.56	3.42

The result of Observations made in 1842, 1843, and 1844, give the same velocity between Dundee and Newburgh, and the following rates between Newburgh and Perth :—

	Time. H.	Time. M.	Distance in Miles.	Rate of Tide-Wave in Miles per Hour.
Newburgh to Carpow, ...	0	25	1.33	3.17 - 3.19
Carpow to Kinfauns, ...	0	55	4.92	5.36
Kinfauns to Perth (Tide Harbour), .	0	20	2.32	6.93 - 6.96
Giving, as a mean for the whole distance from Newburgh to Perth in 1844,	1	40	8.56 - 8.57	5.13 - 5.142
Time from Newburgh to Perth in 1833,	2	30	8.56 - 8.57	3.428

Thus shewing an increase in the velocity of the Tide Wave of more than 1⅝ mile per hour, as the result of the improvements.

N.B.—The elapsed time in Neap Tides at present, between Newburgh and Perth is 1 h. 53 m.

II. *High Water Level.*

The levels of the surface of High Water at different Stations throughout the River have been found to be unchanged, and the following results refer to the years 1833 and 1844:—

From Flisk Point to Balmbreich, there is a fall of	5 inches.	Spring Tides.
... Balmbreich to Newburgh, there is a rise of	7½ ...	
... Newburgh to Perth (Tide Harbour), there is a rise of	18 ...	

From Flisk to Balmbreich, there is a fall of .	2½ inches.	Neap Tides.
... Balmbreich to Newburgh, there is a rise of	6 ...	
... Newburgh to Perth (Tide Harbour), there is a rise of	12 ...	

III. *Low Water Level.*

Rise on the surface of Low Water (Spring Tides) in 1833:—

	Ft.	In.	Distance in Miles.	Rate of Slope per Mile in Inches.
Flisk to Balmbreich, there is a rise of .	0	4	2.04	1.95
Balmbreich to Newburgh, rise of . .	2	8	3.42	9.35
Newburgh to Perth (Tide harbour), rise of	4	0	8.56	5.06

Rise on the Low Water of Spring Tides in 1844:—

	Ft.	In.	Distance in Miles.	Rate of Slope per Mile in Inches.
Newburgh to Carpow, there is a rise of	0	5	1.33	3.75
Carpow to Perth, there is a rise of .	1	7	7.23	2.63
Hence from Newburgh to Perth in 1844,	2	0	8.56	2.80

N.B.—The result of the Observations of 1844, gives a depression on the Level of the Low Water mark on the gauge, of two feet at Perth Tide Harbour.

IV. *Duration of Flood and Ebb.*

The results of observations in 1833 and 1844, at Newburgh, shew that the duration of Flood and Ebb Tides at that place are unchanged. The times are as follow :—

	H.	M.
Spring Tides flow,	4	20
... ebb,	7	20
Neap Tides flow,	4	30
... ebb,	6	45
At Perth in 1833,—		
Spring Tides flowed,	2	20
... ebbed,	7	0
Neap Tides flowed,	3	15
... ebbed,	7	0
At Perth in 1844,—		
Spring Tides flow,	3	10
... ebb,	7	0
Neap Tides flow,	3	10
... ebb,	7	0
Increase of duration of Flood in springs at Perth,	0	50
In 1833 the River ran at its natural level at Spring Tides,	1	45
In 1844 it runs at its natural level at Spring Tides,	1	0
Giving a decrease in the time of standing at low water, or in the absence of tidal influence at Perth at Spring Tides, of	0	45

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